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CLINICAL REVIEW

Supine position related obstructive sleep apnea in adults: Pathogenesis and treatment

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SUMMARY

The most striking feature of obstructive respiratory events is that they are at their most severe and frequent in the supine sleeping position: indeed, more than half of all obstructive sleep apnea (OSA) patients can be classified as supine related OSA. Existing evidence points to supine related OSA being attributable to unfavorable airway geometry, reduced lung volume, and an inability of airway dilator muscles to adequately compensate as the airway collapses. The role of arousal threshold and ventilatory control instability in the supine position has however yet to be defined. Crucially, few physiological studies have examined patients in the lateral and supine positions, so there is little information to elucidate how breathing stability is affected by sleep posture.

The mechanisms of supine related OSA can be overcome by the use of continuous positive airway pressure. There are conflicting data on the utility of oral appliances, while the effectiveness of weight loss and nasal expiratory resistance remains unclear. Avoidance of the supine posture is efficacious, but long term compliance data and well powered randomized controlled trials are lacking. The treatment of supine related OSA remains largely ignored in major clinical guidelines.

Supine OSA is the dominant phenotype of the OSA syndrome. This review explains why the supine position so favors upper airway collapse and presents the available data on the management of patients with supine related OSA.

Introduction

Obstructive sleep apnea (OSA) affects almost one fifth of the adult population[1] in whom it is associated with excessive sleepiness,[2] depression,[3] systemic hypertension,[4,5] the metabolic syndrome,[6] insulin resistance[7] and subsequent cardiac ischemia and arrhythmias.[8]

Within the OSA spectrum, the condition is particularly severe when subjects adopt the supine sleeping position and may occur almost exclusively in this position. Despite important and comprehensive reviews of supine sleep apnea,[9] how the supine position interacts with upper airway anatomy, lung volume, function of upper airway dilator muscles, arousal threshold and ventilatory control instability to bring about upper airway collapsibility is poorly understood. Very few of these physiological parameters have been studied comprehensively in both the lateral and supine sleeping positions to see how they may be affected by moving position.

The high prevalence and severity of OSA in the supine sleeping position has led to the development of a number of treatment strategies for this phenotype of the OSA syndrome. Treatments may be similar to those used in the general sleep apnea population or focus on methods to discourage sleeping supine.

There are still a number of areas where our understanding of supine related OSA is lacking. Longitudinal studies of the effects of supine OSA versus non-supine OSA on morbidity and mortality, physiological studies that observe patients in both the lateral and supine position, and adequately powered randomized controlled trials for the treatment of the condition, are potential foci for future research.

Aim

We review the available evidence relating to the pathogenesis and treatment of supine related obstructive sleep apnea.

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Definitions

The definition used to classify patients with a preponderance of respiratory events in the supine position has varied. Many authors consider that supine OSA is present when the apnea and hypopnea index (AHI) is greater than 5 events/h and respiratory events occur at twice the frequency in the supine sleeping position compared to the non-supine sleeping positions.[10,11] A majority of the papers focusing on the diagnosis and treatment of supine related OSA have adopted this definition.

Mador et al.[12] proposed an alternative definition of supine OSA whereby the ratio of events in the supine position to the non-supine positions must be greater than two to one and the AHI in the non-supine positions must be less than 5 events/h. The authors felt this definition was more clinically relevant given that avoidance of the supine sleeping position by patients who fit this description would result in normalization of the AHI and subsequent relief of symptoms of OSA. The Mador definition has been adopted and modified for use in some studies of treatment of positional OSA by avoidance of supine sleep.[13,14]

For clarity in this paper we will use the following definitions:

1) Supine predominant obstructive sleep apnea (spOSA):
   - Overall AHI is greater than 5 events/h, and,
   - The supine AHI is greater than two times the non-supine AHI.
2) Supine isolated obstructive sleep apnea (siOSA):
   - Overall AHI is greater than 5 events/h, and,
   - The supine AHI is greater than two times the non-supine AHI and,
   - Non-supine AHI is less than 5 events/h.

The time that a patient spends in a specific body position can have an important effect on the AHI in that position.[15,16] The vast majority of the papers in the published literature relating to supine OSA describe a minimum time required in the supine position as an inclusion/exclusion criterion. Typically the minimum time required in the supine and non-supine positions to be included in these studies is between 15 and 30 min.[11–13,17,18] The decision to have a time cut off for the definition of supine sleep apnea is an arbitrary one and the effect of changing the definition to shorter or longer time periods is not known.

Both of the aforementioned definitions are widely used throughout the literature regarding supine OSA. Neither definition, however, acknowledges the potentially confounding role of rapid eye movement (REM) sleep in the generation of obstructive events. It is already well established that the supine AHI rises in REM sleep compared with non-rapid eye movement (NREM) sleep.[19] It follows then, that a disproportionate time spent in the supine sleeping position in REM sleep will increase the likelihood of a patient being classified as having spOSA even if the ratio of events in NREM sleep (which makes up the majority of the night) is less than two to one. This may be an important distinction to make if the mechanisms involved in obstruction in REM sleep are different to those in supine sleep.

Epidemiology

Prevalence

The prevalence of spOSA is variably reported as between 50 and 60% of patients who present to sleep clinics for overnight polysomnography,[11,17,18,20] whereas approximately 25–30% of the same population may be classified as having siOSA.[12,17,21] The prevalence of spOSA in the Asian population is higher than for Caucasians at between 67 and 75%.[22,23] There are no reports of the prevalence of either condition in the general population.

Time spent supine

The time in which a subject sleeps supine is an important determining factor of the overall AHI in patients with spOSA and siOSA. Having spOSA or siOSA does not influence the amount of time spent supine as these patients appear to spend as much time in the supine position as unselected patients with OSA,[17] ranging from 32 to 42.7% of total sleep time[17,18,20,24] for spOSA, 40–48.1% for siOSA[12,21] and 27–48% of total sleep time for patients with non-positional obstructive events.[17,18,20,21,24]

Age and gender also do not influence the time spent supine. With increasing age, fewer position shifts are made over the course of the night,[25] although the time spent supine in a small cross-sectional study did not change markedly across a series of age ranges (apart from early childhood).[25] O'Connor et al. demonstrated that men and women spend a similar amount of time supine during sleep.[26] The amount of time spent in supine sleep in unselected general populations is not known.

The published studies relating to the classification and polysomnographic features of supine OSA are largely based on single night observations. Although the correlation of overall AHI across nights is strong,[27] there is a considerable individual variability in overall AHI using Bland-Altman analysis.[28] It is unclear how much variability in time spent supine contributes to this night-to-night variability in total AHI. Several studies have explored the possible contributors to night-to-night variability in overall AHI,[29–31] including various polysomnographic and demographic features. Although the mean AHI in specific body positions and sleep stages does not change significantly across nights,[28] the individual variability of the position specific AHI from night-to-night has not been reported.

Clinical features

Like OSA in general, spOSA is more likely to be seen in men than women. The male to female ratio is 11.1:1 for all severities of OSA,[26] and 2.6:1 in mild-moderate OSA,[17] with the discrepancy between these figures likely arising from the increased male prevalence of severe OSA.[26]

Patients with spOSA differ from non-positional patients: their body mass index (BMI) is less at 29.3–31.6 kg/m^2 [11,12,17] versus 31.9–38 kg/m^2,[11,12,18] and their ages differ at 49.5 - 52.9 y[11,17] versus 54.9-59.2 y.[11,12] These differences in BMI and age hold true for siOSA patients compared to non-positional patients,[12] even when controlling for the lower overall AHI found in the siOSA group.[17]

One of the most common presentations to the sleep physician is loud snoring. It has long been recognized by patients and their partners that the loudness of snoring is worse when supine.[32] As distinct from OSA, simple snoring without apnea is louder and more frequent in the supine sleeping position.[33] The distinction between simple snoring and spOSA and siOSA is an important one in the context of body position and the goals of treatment. As discussed in the treatment section of this article, positional therapies for siOSA and spOSA may not reduce complaints of snoring,[13] unless the snoring is louder or occurs predominantly in the supine position.

Supine predominant patients have been reported as subjectively more sleepy[17] than other OSA patients, whereas with siOSA patients no differences are reported.[12] Conversely, with regard to objective determinants of sleepiness, multiple sleep latency test (MSLT) data from Oksenberg et al.[11] demonstrate a trend toward reduced sleepiness in spOSA patients compared to non-positional

OSA patients, although these data are confounded by the fact that the non-positional patients had more severe OSA (respiratory disturbance index in the non-positional group of 44.0 events/h versus 27.8 events/h in the spOSA group, $p < 0.05$).

Obstructive events observed on polysomnographic recordings are more severe in the supine position.[34] In patients with severe non-positional OSA, apnea duration and degree of oxygen desaturation are both more severe when the patients are observed in the supine sleeping position.[34] The typical polysomnographic features of non-positional and positional OSA patients are demonstrated in Fig. 1.

Recording of position

Despite the clear influence of the supine position on OSA, there are surprisingly few data as to how body position is recorded and the accuracy of body position sensors is unknown. Early studies on the effect of body position on sleep disordered breathing used direct observation and recording overnight[10,18] and video recording with manual recording of position.[25] Using video recording it has been shown that the time spent supine may be over-estimated in a sleep laboratory because of the restriction on movement by the polysomnographic instrumentation used.[35] Later studies use position sensors with or without correction using video monitoring. The American Academy of Sleep Medicine manual for the scoring of sleep and associated events contains little information on the scoring of body position during sleep. The sole recommendation is for a signal acquisition frequency of 1 Hz.[36] Very few studies have compared the accuracy of the various trunk position sensors in use with video monitoring. Furthermore, head and neck position can influence AHI independent of trunk position,[37] and there is likely to be a continuous relationship between the degree of supine versus lateral trunk position and AHI[38] – two additional factors which are not recorded by standard trunk position sensors, which tend to treat body position as a categorical variable. The issue here is that handling all possible trunk sleeping positions as either supine or non-supine ignores the likely graded effect of trunk rotation from supine to lateral on the collapsibility of the upper airway.

Pathogenesis

OSA is characterized by recurrent obstruction of the upper airway during sleep. Several mechanisms have been identified in the generation of upper airway obstruction, including passive airway characteristics as determined by anatomical structures and the pharyngeal critical closing pressure (PCrit), the role of lung volume and tracheal tug, the action of airway dilator muscles such as genioglossus, ventilatory control instability and arousal threshold (see Fig. 2). These factors may be understood as interacting to varying degrees in patients across the night.[39] By evaluating the effect of the supine body position on each of these factors it may be possible to understand why a given patient obstructs more frequently and with greater severity in the supine compared to the lateral position. It is important to acknowledge that the majority of data presented here has been collected from male subjects, which is a deficit in the OSA literature in general.

Gravity

Before discussing each of the pathogenic mechanisms of supine related OSA it is important to recognize the effect of gravity on the respiratory system. A change of body position from lateral to supine results in a 90° long axis shift in the directional effect of gravity on the structures of the respiratory system which is likely to underpin many of the physiological changes observed when moving from one position to another. This is supported by a small study of weightlessness on the AHI in astronauts.[40] During this study it was observed that the AHI in zero gravity was lower than when recordings were made in standard gravity. The authors of this paper attributed the observation to changes of zero gravity on upper airway structures rather than lung volume and this is supported by a later study demonstrating that lung volume does not change significantly in zero gravity compared to standard gravity.[41] Interestingly, this study demonstrated a significant change in lung volume when changing position from upright to supine or 30° tilt under the conditions of standard gravity.

Airway anatomy

A number of anatomical features of the upper airway contribute to obstruction in OSA patients. Ultimately, airway lumen size and shape and anatomical propensity to collapse are determined by the interaction between a number of factors such as the size of the bony enclosure (mandible, maxilla, cervical spine),[42] the size of the soft tissues (tongue, soft palate, lateral pharyngeal fat pads)[43] and the shape and folding characteristics of the airway.[44]

The narrowest site of the airway in normals and OSA patients is generally accepted to be the velopharynx.[45,46] Contributors to narrowing of the velopharynx in OSA subjects include the tongue, soft palate and lateral pharyngeal fat pads.[43] Given the propensity for collapse in the supine sleeping position several studies have imaged the upper airway in detail in the seated, lateral and supine

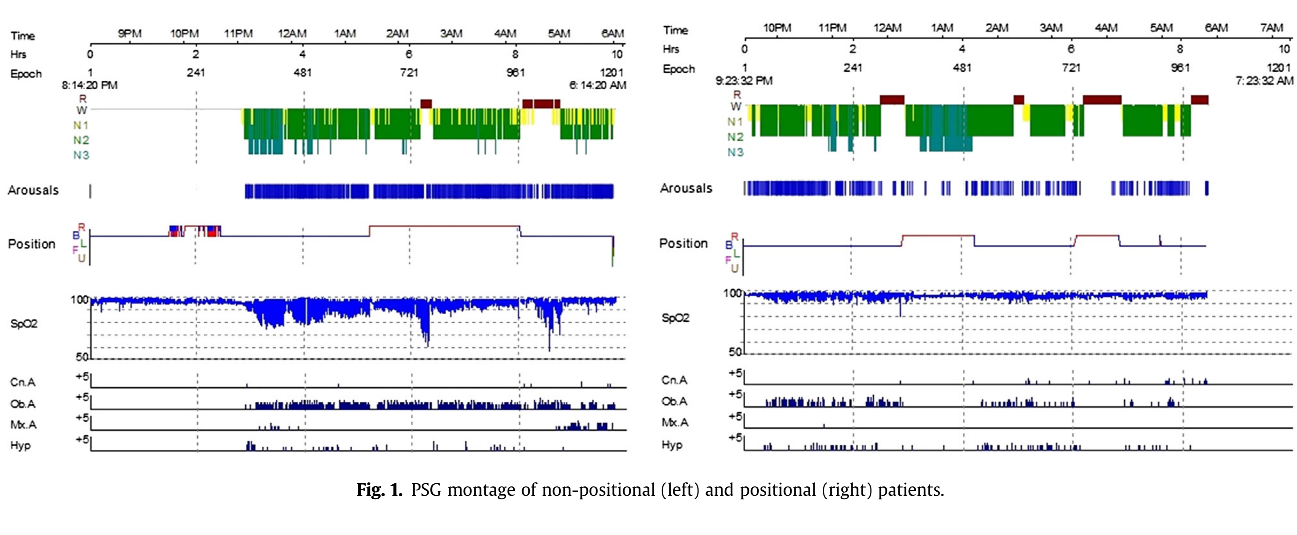

Fig. 1. PSG montage of non-positional (left) and positional (right) patients.

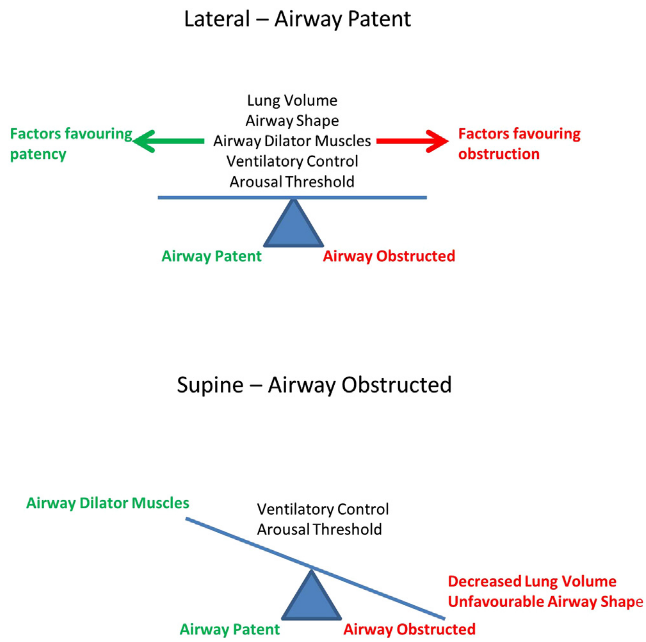

Fig. 2. Physiological changes from the lateral sleeping position to the supine sleeping position. This figure demonstrates the decrease in total lung capacity when moving from the upright to supine position. The decrease is largely a result of a fall in vital capacity and expiratory reserve volume. Abbreviations: ERV, expiratory reserve volume; IRV, inspiratory reserve volume; RV; residual volume; TLC, total lung capacity; TV, tidal volume; VC vital capacity.

position in order to examine the effect of gravity on the soft tissue structures and relationship of the bony enclosures. The literature is somewhat conflicting with regard to anatomical changes from lateral to supine, which is likely to represent differences in methodologies regarding imaging modality and acquisition of orthogonal images, head and neck position, controlling for phase of respiration, sleep state of the subjects and the population under examination.

Normal subjects have a significant decrease in pharyngeal cross-sectional area (CSA) when moving from seated to supine but not from lateral to supine.[47] When unselected OSA patients move from lateral to supine some studies demonstrate no significant change in CSA,[47–50] while others show a small but significant change.[42,51] Technical differences are likely to explain the different findings including the use of anesthetic, ventilation of the patients, and direct endoscopic examination with conversion of maximal CSA images to measurements based on pixel sizes[42] and the averaging of CSA over a number of breaths.[51] Both positional and non-positional sleep apnea patients have an elliptically shaped airway in the supine position with the long axis oriented laterally.[46,48,49,52] By contrast, there is evidence that some patients with severe non-positional OSA have an elliptically shaped airway that is oriented in the antero-posterior direction.[53,54] Once again, the patients selected, the imaging modalities utilized and the methodology applied were widely varied across papers. Importantly, studies that select for spOSA or siOSA subjects, use matched controls, or image subjects both supine and lateral while asleep are lacking. Controlling for the phase of respiration is also important.

The relationship of the bony enclosure of the upper airway is an important determinant for how the soft tissues of the upper airway contribute to lumen narrowing.[42] Clearly the starting configuration of the bony enclosure as encompassed by size and orientation of the maxilla, mandible and cervical spinal column are important. Patients with supine OSA (defined as supine AHI greater than two times lateral AHI and lateral AHI less than 15 events/h in this case) have been shown to have a relatively small craniofacial volume on three-dimensional magnetic resonance imaging (MRI) modeling compared to age and BMI matched non-positional patients.[55] The small volume likely results from the lower facial height and more backward position of the jaw in positional patients.[55] The relationship between bony structures enclosing the upper airway may change through either alteration in neck flexion or mandibular opening in order to change patency of the lumen.[56] Although movement of the mandible during sleep has been studied, somewhat surprisingly, sleep stage rather than body position was found to have a larger effect on mandibular opening in normal subjects.[57] Further investigation of the dynamic jaw and neck movements of patients with spOSA and siOSA during supine and lateral sleep are required to clarify the contribution of the bony enclosure to these forms of OSA.

From a purely anatomical perspective, differences in airway shape rather than CSA may be more important in generation of airway obstruction in the supine rather than the lateral sleeping position in patients with spOSA and siOSA. Advanced models of the upper airway utilizing flow-field computations analysis, and modified Starling-resister models where tissue compliance is accounted for, may help to explain this observation.[44,58] Amatoury et al. report that the airway folding characteristics may be more important than CSA in causing obstruction.[44] In terms of geometry, flow-field computation analysis has demonstrated that changes in soft palate displacement and side wall deformation (e.g., with the more elliptical airway shape of the supine position) may generate altered pressure gradients in the velopharynx and therefore increase the propensity to collapse.[58] This modeling is particularly interesting as it not only demonstrates how shape may predispose to collapse, but also supports the observation that increasing lateral pharyngeal fat pad size increases risk of OSA[43] – lateral low pressure areas are steepened as the airway is narrowed by enlarging the side walls.[58] Another avenue by which airway shape may affect airway function is through modulation of the effectiveness of upper airway muscles such as genioglossus[59] – the function of which is examined subsequently.

Pharyngeal critical closing pressure (PCrit)

The PCrit of the upper airway quantifies the overall collapsibility of the upper airway in a given patient[60] and is widely considered a superior measurement to static imaging and measurements of resistance. The measurement can be made while patients are asleep and can be repeated over the course of the night in different body positions.[61] The technique of PCrit measures the pressure of the upper airway at which collapse and obstruction occur, with a more positive measurement indicating a more collapsible airway.

In contrast to the imaging literature, the PCrit literature is more consistent when examining changes from lateral to supine body position. Several studies have demonstrated a more positive PCrit (and therefore more collapsible airway) in the supine position compared to the lateral position in male OSA patients.[61–64] The difference in PCrit is typically in the order of 2.2–2.9 cmH_2O in OSA patients in NREM sleep,[61,63,64] although a larger difference was found in anesthetized OSA patients.[42] Importantly, there are no published data on how PCrit changes from lateral to supine specifically in spOSA patients or siOSA compared to non-positional OSA patients or controls. It seems highly likely these patients would have an even greater positional change in PCrit compared to unselected OSA patients. Factors leading to the decrement in PCrit in the supine position are a less favorable airway shape (as discussed above) and a reduced lung volume.[65]

The influence of head, neck and jaw position on PCrit and the severity of OSA in spOSA and siOSA patients are unknown. As there

is no standardized way of recording head, neck and jaw position on overnight polysomnography these parameters are largely ignored, despite their known effect on the collapsibility of the upper airway in normal subjects.[62,66,67]

Lung volume

Lung volume is an important variable in sleep apnea as it is known to influence upper airway stability, in normal subjects[68,69] and OSA patients,[70] via caudal tracheal displacement and subsequent changes in upper airway tissue pressure, as demonstrated in dog, cat and rabbit models.[71–73]

Lung volume is reduced significantly both with increasing BMI and on adopting the supine position. When normal subjects move from upright to supine there is a fall in functional residual capacity (FRC),[74–77] total lung capacity (TLC), expiratory reserve volume (ERV) and vital capacity (VC) without a change in residual volume (RV),[77] see Fig. 3. Few studies address the effect of lateral positioning on lung volume, but in normal subjects ERV[75] and FRC[78,79] fall and dynamic lung compliance increases[80] when moving from the lateral to the supine position.

When moving from upright to supine FRC falls in overweight patients with OSA.[81] A cross-sectional study of seated lung volumes demonstrated a linear decrease of TLC with increasing BMI,[82] although the values did not lie outside the predicted range. However, ERV and FRC decreased exponentially with increasing BMI over the 25–30 kg/m^2 range,[82] which corresponds closely to the mean BMI of supine predominant OSA patients.[17] This study supports the possibility of a BMI dependent interaction with lung volume in subjects up to a BMI of 30 kg/m^2. The lung volume changes within this range of BMIs may be secondary to increasing abdominal fat distribution and increasing intra-abdominal pressure, which has been shown to influence FRC in anesthetized obese individuals.[83] By contrast, the FRC does not fall in the morbidly obese (BMI $>$ 40 kg/m^2) when moving from upright to supine.[84,85] The balance of elastic forces of the lung and chest wall in these patients gives rise to lower lung volumes. As a result, FRC and ERV[86] are smaller than predicted in the seated posture, but change less compared to non-obese controls when adopting the supine position[84,85] as the morbidly obese are already breathing at, or near, RV in the upright posture. Lung volume changes when moving from lateral to supine in the obese have not been studied.

A number of studies have examined the effects of changes in lung volume on upper airway stability in subjects lying supine during sleep.[65,69,87–89] In 19 young normal subjects, reductions of 600 mL in end expiratory lung volume (EELV), as measured with magnetometers, increase PCrit by 1.1 cmH$_2$O (rendering the airway more collapsible) despite an increased activation of genioglossus.[69] Tagaito et al. demonstrated the same interaction between lung volume and PCrit in reverse. In seven OSA patients Tagaito et al. increased lung volume by 720 mL which resulted in a fall in PCrit by 1.2 cmH$_2$O[89]; importantly this effect was independent of upper airway neuromuscular input as patients were anesthetized and paralyzed. Stadler et al.[90] increased the intra-abdominal pressure in 15 obese (BMI 34.5 kg/m^2) male OSA patients while sleeping in the supine position by inflating a pressure cuff around the abdomen. As a result, EELV fell by 530 mL and PCrit increased by 1.4 cmH$_2$O. This paper ties in the potential interaction between increasing BMI, decreasing lung volume and increasing collapsibility of the upper airway.

There are no published studies that investigate the effect of moving from the lateral to the supine body position on the *interaction* between EELV and PCrit, either in OSA patients in general or in selected OSA phenotypes such as spOSA.

Upper airway dilator muscle function

The ability of upper airway dilator muscles, in particular genioglossus, to compensate in the face of collapsing forces is a key determinant of upper airway patency. Patients with OSA have increased baseline genioglossus activity,[91] most likely in compensation for unfavorable airway size and shape and reduced lung volume with resultant increased PCrit. The activity of genioglossus decreases at sleep onset[92] and subsequent increases in its activity while asleep can help protect against obstruction.[88] The variable activity of genioglossus while asleep helps explain why some patients experience obstructive events at different times during the night.[93]

Body position is known to have a significant influence on the function of genioglossus, as does the route of breathing.[94] Takahashi et al. demonstrated that genioglossus activity was increased in oral as compared to nasal breathing. Genioglossus activity is greater in the supine compared to both the upright[94–97] and the lateral position in both normals[97] and OSA patients.[98] The magnitude of this compensatory response has not been quantified in patients with spOSA or siOSA compared to other OSA patients or controls.

Thus the activity of genioglossus is increased in the supine position to protect the airway when it is at its most vulnerable and when the muscle is likely to have maximal beneficial effect; that is, when lying supine, tongue protrusion secondary to genioglossus contraction will maximally enhance upper airway caliber. The responsible mechanism by which genioglossus is activated in the supine position is not entirely clear, but stimulating the vestibular apparatus results in augmented genioglossus electromyogram (EMG) activity in cats.[99] Additionally, when the subjects in the Otsuka et al. study lay with the trunk supine but with the head rotated laterally the genioglossus EMG activity was not significantly different from when the subjects were lying in the lateral

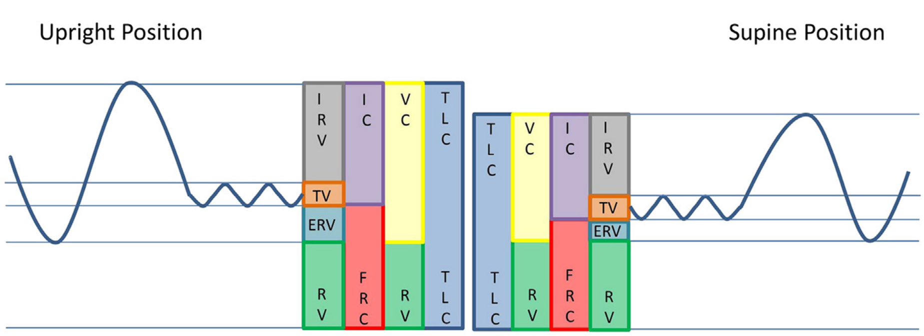

Fig. 3. Lung volume changes from upright to supine.

recumbent position (both head and trunk oriented laterally).[97] In both of these positions the vestibular apparatus is oriented in the same plane, and the observed muscle response is of similar magnitude.

It is not clear if the genioglossus response in patients lying supine is attenuated in spOSA compared to other forms of OSA or controls, as no studies have addressed this particular group. It may be that the muscle does not activate sufficiently to compensate for other unfavorable physiology in the supine position and it would be possible to measure this by comparing the genioglossus EMG response to a position change from lateral to supine.

Ventilatory control

Disturbances of the ventilatory control system could contribute to the pathogenesis of OSA by creating excessive responses in pump and resistance muscles to respiratory disturbances. Such high loop gain states create oscillations in drive to the respiratory muscles and thereby favor upper airway collapse when drive is at its minimum. Ventilatory control instability will predispose to obstruction in patients with a susceptible airway, for instance one with a PCrit close to atmospheric pressure.[100]

The effect of body position on ventilatory control instability in OSA patients has not been studied. However, with respect to central sleep apnea a number of studies have demonstrated a worsening of Cheyne-Stokes respiration in patients with cardiac disease when lying in the supine position compared to the lateral position.[101,102] Reduced lung volume with adoption of the supine position has been postulated as the cause of the high loop gain and subsequent respiratory instability,[101,102] although change in lung volume in this patient group has not been directly measured and is disputed by some.[103]

The overall contribution of ventilatory control instability to the generation of obstructive respiratory events in the supine compared to lateral position is not known. It may be that the reduced lung volume seen in the supine position contributes to ventilatory instability via an increased plant gain in some OSA patients, but this remains to be proven.

Arousal threshold

Arousal from sleep is protective in OSA as it allows resolution of obstructive respiratory events and re-instatement of ventilation. However, given that a significant proportion of patients are able to achieve stable flow limited breathing through recruitment of upper airway dilator muscles,[93] arousal from sleep is not essential to terminate an obstructive event. In patients with a low arousal threshold the arousal response itself may potentially be maladaptive as it can exacerbate instability and worsen OSA. Pharmacological manipulation of the arousal threshold is now being considered as a means to improve the severity of sleep disordered breathing in these patients.[104]

The key initiating stimulus to arousal in OSA is thought to be respiratory effort, as measured by esophageal pressure (Pes).[105] One may hypothesize that a higher Pes is generated in supine sleep as the subject tries to overcome the reduced lung volume in the supine position, however the threshold response to rising Pes has also not been compared in the lateral and supine position. It has been observed that respiratory events are more severe in the supine position both in duration and level of oxygen desaturation. Whether it simply takes longer to overcome the unfavorable physiology of the supine position or if arousal threshold rises in the supine position to permit more severe OSA is not clear. More basic research is required to elucidate the effect of body position on arousal threshold in OSA patients.

Treatment

The treatment of spOSA and siOSA can be divided into two broad categories: treatments that focus on avoidance of the supine sleeping position and treatments that have been used generally in the management of OSA. Although a number of papers have addressed the efficacy of these various treatment forms, the studies are generally underpowered and long term efficacy and follow-up data are lacking. In addition, some studies are weakened by a lack of control of the time spent supine in pre- and post-treatment sleep studies and the subsequent effect this has on overall AHI, which is often used as an outcome measure.

Supine sleep avoidance

If sleep disordered breathing is worse in the supine position then it follows that avoidance of supine sleep should improve the AHI, especially if the non-supine AHI is not elevated (for example, in patients with siOSA). Several strategies have been tested in aiding avoidance of supine sleep with varying success as reviewed recently.[106] Determinants of effectiveness include efficacy at avoiding the supine position and the lateral AHI of the subjects selected. However, the extent of lateral trunk rotation achieved by the treatment, as well as the head and neck position are further important factors which are often overlooked. Using response surface analysis, Lee et al.[107] have shown that in 25 spOSA patients that the optimal position for avoidance of spOSA is greater than 40° lateral rotation with greater than 70 mm of cervical heat tilt support and an elevation underneath the scapula of 30 mm.

The "tennis-ball technique" is often reported by clinicians as a relatively simple and cost-effective method of supine sleep avoidance. In this strategy a tennis ball is held over the patient's back either with a sling, a pocket sewn into a t-shirt or cloth belt. The rationale is that whenever patients roll onto their back the discomfort of lying on the tennis-ball forces them to roll onto their side. Oksenberg et al.[108] recruited 12 spOSA patients who had refused continuous positive airway pressure (CPAP) therapy and applied a cloth belt which held a tennis ball in the middle of the subjects' back and repeated the polysomnogram with the device in situ. Time spent supine reduced from 79% on the diagnostic night to 12.3% on the treatment night – leading to a reduction in overall AHI from 46.5 events/h to 17.5 events/h. Interestingly, the average of 79% supine sleep in the diagnostic study is much higher than in most other reported studies[17,18,20,21,24] and may have led to an overstatement of the treatment effect. In another study, Skinner et al.[109] conducted a randomized cross-over trial comparing a modified tennis-ball technique to CPAP in 20 positional OSA patients. The patients were diagnosed with mild-moderate OSA and selected on the basis of twice as many events in the supine sleeping position and a non-supine AHI of $<$10 events/h. Although there were no differences in Epworth sleepiness scores (ESS) or Functional Outcomes of Sleep Questionnaire, CPAP was more effective at reducing the AHI (from a mean of 22.9 events/h in both groups prior to treatment to 4.9 events/h versus 12.0 events/h). In this study, the modified technique reduced supine sleeping from 34.4% to 6.3%. In addition to reducing time spent supine, the "tennis-ball technique" has been shown to reduce 24-h blood pressure in a small sample of patients with spOSA.[110] Thus long term treatment of supine related OSA could improve cardiovascular outcomes, although findings need to be replicated in a larger sample with a longer follow-up period.

The main problem with the simple "tennis ball technique" is poor short and long term adherence to treatment, primarily due to discomfort. In the Berger et al. study[110] 5/18 selected patients were unable to comply with the treatment over a one month period for

various reasons and in the Oksenberg et al. study,[108] only 38% of responders reported ongoing use of the technique at 6 mo. In another study of long term compliance with the tennis-ball technique, less than 10% of patients continued treatment after an average follow-up time of 30 mo.[111]

Because of the discomfort associated with the tennis-ball technique, and its variants, a number of other strategies to avoid supine sleep have been explored and have shown reasonably good short term success. Jokic et al.[112] conducted a randomized cross-over trial comparing a positioning device with CPAP for a trial period of 2 wk each. The study included 13 patients with siOSA and the device consisted of a back pack with a large 30 cm semi-rigid foam cushion inside. The device prevented supine sleep in all patients although the authors report semi-supine sleep in some of the subjects. Both CPAP and the positional therapy were effective in reducing the overall AHI in these selected subjects, with CPAP being more effective. ESS, maintenance of wakefulness test (MWT) results, cognitive performance and mood were not significantly different between CPAP and positional therapy, although with small numbers a type 2 error cannot be excluded. Seven of the 13 patients preferred CPAP therapy. Loord and Hultcrantz[14] used a device called "the Positioner" in 23 patients with siOSA. The device consisted of a horizontal board placed under a pillow to which the patient is physically strapped by way of a tight fitting vest. Although effective at preventing supine sleep, five of the 23 could not tolerate the treatment. Interestingly, recordings of noise while using "the Positioner" in situ demonstrated an increase in snoring, the cause of which was not clear. In a similarly designed study, Zuberi et al.[113] demonstrated in 22 patients (19 of whom had mild-moderate OSA) that the use of a pillow that prevents supine sleep resulted in a reduction in AHI and snoring. Use of other simple pillows to avoid the supine position is likely to be quite prevalent but no data are available as to their effectiveness and comfort.

Permut et al.[114] recruited 38 siOSA patients and randomly assigned them to a night of CPAP or a positional device followed by a second night utilizing the other treatment. The device was worn around the chest and comprised a foam block embedded in a synthetic belt: its use reduced supine sleep from 40% to 0% and resulted in a reduced AHI that was equivalent to that achieved with CPAP usage. On a single night the device was very effective, however no long term compliance or efficacy data was collected. A less bulky device able to record time spent supine via an internal position-sensitive tilt switch was tested by Bignold et al.[13] The device is embedded within a belt strapped around the chest and whenever the patient moves supine a vibration is delivered to the sternum that alerts the patient and allows them to move to the lateral position. The device reduced the percentage of sleeping time spent supine from 36.4% to approximately 1% in positional OSA patients with a subsequent 45% reduction in AHI. The recording capabilities of the device allowed for objective measurements of compliance and demonstrated over a 3-wk period that the device was worn 85% of the time. Snoring was not reduced and bed partners reported increased disturbance. This raises an important issue that is likely to affect long-term compliance of all positioning devices – if the trigger to seek medical attention is disruptive snoring rather than other OSA symptoms, ongoing snoring (despite adequately treated OSA) is likely to lead to patient dissatisfaction with the treatment.

In summary, in selected patients with mild-moderate siOSA a number of body positioning devices are efficacious in the short term at reducing the time spent supine and, subsequently, the overall AHI. Some of these devices appear equivalent to CPAP in their ability to improve daytime symptoms of OSA and the overall AHI, but patient numbers in these studies have been very small. The devices used vary significantly in patient comfort and cost, do not resolve residual snoring in the lateral position, and there is no evidence of good long term compliance for any of the devices. Further research into the ongoing effectiveness and, in particular, long term compliance of body positioning devices is needed before their use could become more widespread.

Effect of general OSA treatments on supine OSA

A number of treatments developed for OSA have been trialled in the context of patients suffering from supine OSA. CPAP, oral appliances, nasal expiratory resistance therapy, surgery and weight loss have all been studied in the context of OSA and their application to the spOSA and siOSA population is reviewed here.

Continuous positive airways pressure

CPAP is the recommended first line treatment for moderate to severe OSA.[115] As discussed above, CPAP therapy has been compared to a number of positional therapies for spOSA. It is superior to most positional therapies at reducing the overall AHI, it resolves all snoring and has beneficial effects on a number of sleepiness and quality of life metrics. CPAP is preferred by patients to positioning devices in some studies[112] although the finding is not universal.[114] With regard to implementing fixed pressure CPAP therapy, it is critically important that patients are observed in the supine position while titrating the CPAP therapy in those with spOSA and siOSA. This enables a pressure to be selected which will treat the periods of most significant upper airway obstruction. An alternative approach to commencing CPAP therapy is to use ambulatory auto-titrating positive airway pressure (auto-PAP) therapy. Although no more effective than fixed pressure CPAP in unselected OSA patients,[116,117] auto-PAP may lead to better outcomes in spOSA.[118] Series and Marc[119] studied the effect of auto-PAP versus fixed pressure CPAP on patients with body specific or sleep stage dependent OSA. The outcomes studied were ESS, MWT and compliance. Over a 3-wk period, patients with sleep stage or supine predominant OSA treated with auto-PAP therapy performed better on MWT and ESS. Although the treatment period was short and a proportion of the data was historical, using the lowest possible CPAP pressure for each sleep stage or body position could lead to better treatment tolerance. However, this issue requires confirmation with further research before auto-PAP can be widely recommended ahead of fixed pressure CPAP for spOSA.

Oral appliances

A number of studies have demonstrated that oral appliances are particularly effective at treating obstructive events that occur in the supine position.[120–123] Supine dependent OSA is a predictor of treatment success with oral appliances in men[124] and patients with spOSA respond better to oral appliances compared with non-positional patients even when controlling for the overall AHI.[125] The mechanisms by which oral appliances improve supine OSA are likely related to improving the shape and size of the velopharynx[126–129] and augmenting the inspiratory related activity of the genioglossus muscle.[130] The finding of improvement in supine related respiratory events with application of oral appliances is not universal, however.[131] Potential sources of outcome differences include the criteria by which events were scored, the nature of the oral appliance and how it affected route of breathing and mouth opening and jaw position. As noted earlier, mouth opening can increase upper airway collapsibility.[62] Further research on the effect of oral appliances on supine OSA will need to account for these factors so that it may be

determined if certain types of oral appliance are more effective for supine sleep than others.

Weight loss

Significant weight loss has been associated with large improvements in AHI[132–134] although many of the published studies do not analyze the effect of weight loss on obstructive events occurring in the supine sleeping position. Kansanen et al.[135] demonstrated a significantly reduced oxygen desaturation index in the supine position without a significant change in the respiratory disturbance index in the supine position in a cohort of 15 overweight patients with severe OSA who undertook a three-month course of very low caloric intake. In a prospective randomized trial of weight loss in overweight patients with mild OSA, Tuomilehto et al.[136] demonstrated that the overall AHI was improved by weight loss. However, when analyzed according to body position the supine AHI did not change significantly with weight loss. Indeed, it was the non-supine AHI that reduced significantly and largely accounted for the change in overall AHI. This finding is supported by recent data from Oksenberg et al. who found that weight loss reduces the non-supine AHI while, conversely, weight gain increases the non-supine AHI.[137] These studies raise the likelihood that weight loss in patients with OSA preferentially reduces the non-supine AHI. Further work is needed to elucidate the mechanisms underlying this selective improvement in OSA.

Nasal expiratory resistance therapy

The application of a nasal expiratory resistance device has recently been shown to be efficacious in the treatment of OSA[138] and is effective in reducing the supine AHI.[139] Although it has not been applied specifically to patients with spOSA or siOSA it may be that patients with positional OSA respond more favorably to this form of treatment.[140] Given that the device is thought to increase end expiratory lung volume[141] it seems plausible that patients whose lung volume falls when supine may benefit the most from this sort of treatment. Further research of this new therapy in spOSA and siOSA phenotypes is needed to address this question.

Upper airway surgery

The importance of supine related obstructive events in the surgical literature has been noted[142] but there are few data published regarding the effect of upper airway surgery on the development of obstructive respiratory events in the supine sleeping position. Kwon et al.[143] have demonstrated that a uvula preserving uvulopalatopharyngeoplasty reduced the AHI in the supine position in patients with moderate and severe OSA, but further work is needed. Indeed, current recommendations by the American Academy of Sleep Medicine (AASM) highlight the lack of rigorous examination of the effectiveness of various surgical modalities in treating OSA overall.[144]

Combination treatment

The possibility of combining various treatment modalities has not been explored in the form of randomized controlled trials. The idea appeals in that supine avoidance and a second modality may benefit those patients with spOSA who have a residual non-supine AHI greater than 5 events/h or in whom residual snoring is an issue.

Conclusion

Many patients with OSA spend a substantial proportion of time sleeping in the supine position. Obstructive events are commonly more severe and frequent in the supine sleeping position and up to 60% of OSA patients can be classified as having supine predominant OSA. Given that spOSA and siOSA patients comprise the majority of patients with OSA it is surprizing that the long term sequelae of this patient cohort is unknown.

The mechanisms underlying the increased frequency and severity of OSA in the supine position are likely to be a combination of unfavorable airway geometry with an increase in collapsibility, reduced lung volume and an inability of the airway dilator muscles to adequately compensate. The role of arousal threshold and ventilatory control instability in the supine position remains to be elucidated. Most of the reported physiological data pertains to male subjects and there is a deficit of information on the pathogenesis of spOSA and siOSA in women. There is a paucity of studies examining the effect of the lateral position on a number of physiological parameters and, as such, it remains to be seen which of the contributing factors is most important in causing obstruction when moving from the lateral to the supine position.

The effectiveness of positional treatment of supine OSA is dependent on the ability of the method to maintain comfortable non-supine sleep and the subject's non-supine AHI. In the right circumstances it may be equivalent to CPAP therapy on a number of end points, but data on long term success and compliance is either lacking or suggests that adherence to treatment is poor. The application of oral appliances favorably alters upper airway geometry and dilator muscle function and may be beneficial for a proportion of patients suffering spOSA. Although weight loss appears beneficial at reducing OSA severity overall, benefit seems to be preferentially limited to non-supine sleep and may therefore have limited success in supine predominant OSA. There is minimal evidence that upper airway surgery has a beneficial effect on the generation of supine related obstructive events. The role that new therapies such as nasal expiratory resistance therapy play in the specific management of supine predominant OSA remains unclear at this stage.

In conclusion, supine predominant and supine isolated OSA are important and common phenotypes of the OSA syndrome. Further research is required to fully elucidate the contributory mechanisms at play and to determine the best way to treat patients who present with this condition.

Practice points

1) Supine predominant obstructive sleep apnea (spOSA) is defined as:
   - Overall AHI is greater than 5 events/h, and,
   - The supine AHI is greater than two times the non-supine AHI.
2) Supine isolated obstructive sleep apnea (siOSA) is defined as:
   - Overall AHI is greater than 5 events/h, and,
   - The supine AHI is greater than two times the non-supine AHI and,
   - Non-supine AHI is less than 5 events/h.
3) spOSA is present in approximately 50–60% and siOSA in 25–30% of patients who undergo diagnostic polysomnography.
4) There are important clinical and pathophysiological differences between spOSA and siOSA patients and unselected or non-positional OSA patients.
5) Treatment of spOSA and siOSA needs to be tailored to the individual patient but may comprise positional therapy or a number of general OSA treatments such as CPAP or oral appliances.

Research agenda

1) Develop an industry standard for the measurement of body position in the sleep laboratory setting.
2) Measurement of sleeping position in a normal population and including head, neck and trunk position.
3) Longitudinal data exploring the effect of supine obstructive events on the many conditions associated with OSA.
4) Physiological studies aimed at elucidating the mechanisms of OSA that examine subjects in both the lateral and supine position.
5) Adequately powered, randomized controlled trial data exploring the treatment options for spOSA and siOSA.
6) Long term compliance data for the common treatments employed in spOSA and siOSA.

Conflict of interest

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